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GEORGE R. BROWN CONVENTION CENTER

Gear lateral vibrations caused by VSD interharmonic interference with torsional natural frequencies

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Bio

Mr. Staffan Lundholm is a Principal consultant in the machinery dynamics team of Lloyd's Register Consulting. His main tasks include project management, measurement campaigns, computational verification and prediction of rotating equipment within the Oil & Gas industry. He was awarded with his master thesis by the Royal Institute of Technology Stockholm in 2007 in collaboration with Lloyd's Register Consulting.

Dr. Niklas Sehlstedt is since 2013 team leader for the machinery dynamics team of Lloyd's Register Consulting. He first joined the company (then named ODS) in 2005 and worked as a machinery dynamics consultant for the oil and gas industry until joining Dresser-Rand in 2011 as the rotordynamics manager. He holds a Ph.D. in M.E. from Royal Institute of Technology in Stockholm, Sweden.

Rasmus F. Kristensen is part of the Lloyd's Register Consulting Machinery Dynamics Team and is a specialist in mechanical and structural dynamics and in machinery and rotor dynamics in particular. Rasmus is involved in vibration measurements and troubleshooting of rotor dynamic problems in turbomachinery and structural dynamics by use of a wide range of instrumentation

Mr. Leif I. Myklebust (M.Sc). Worked previously (2005-2010) for LR (ODS). Currently Principle engineer in Statoil, Norway. Specialist in condition monitoring, trouble shooting, performance calculations and diagnostics of machinery faults. Focusing on contributing to shift Statoil's maintenance philosophy from time-based and reactive maintenance over to a reliable Condition-Based approach (CBM).

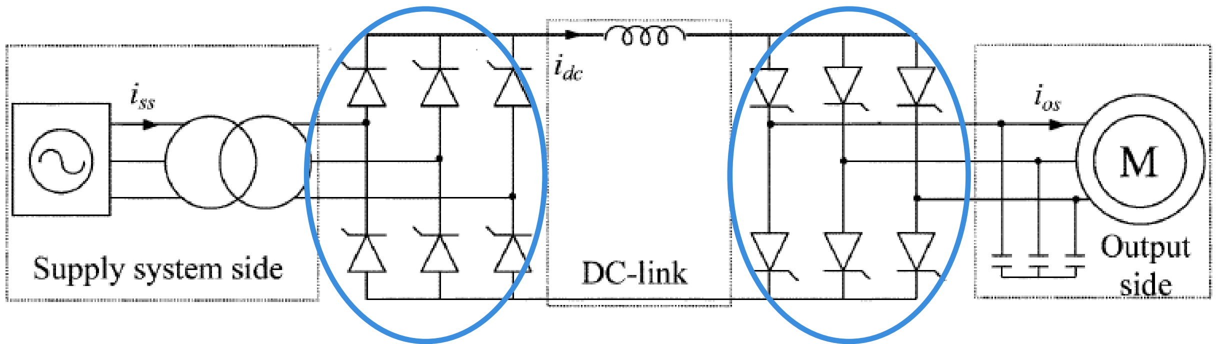
Outline

- Background
- Fundamental theory
- Case
- Discussion

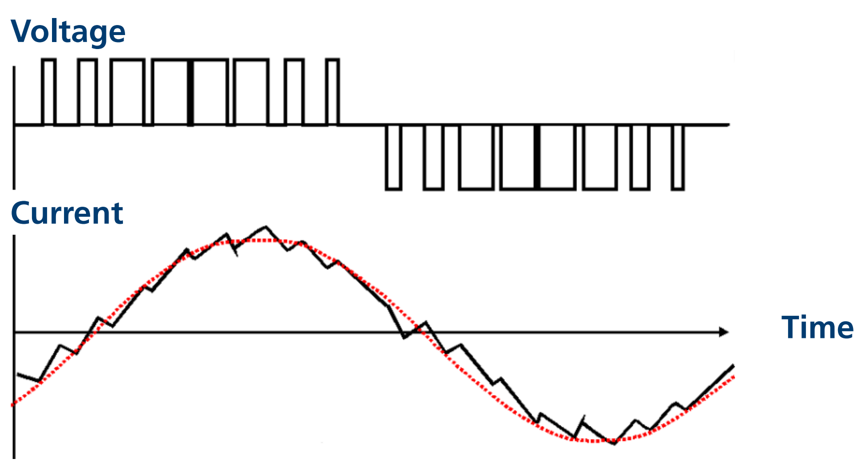
Background

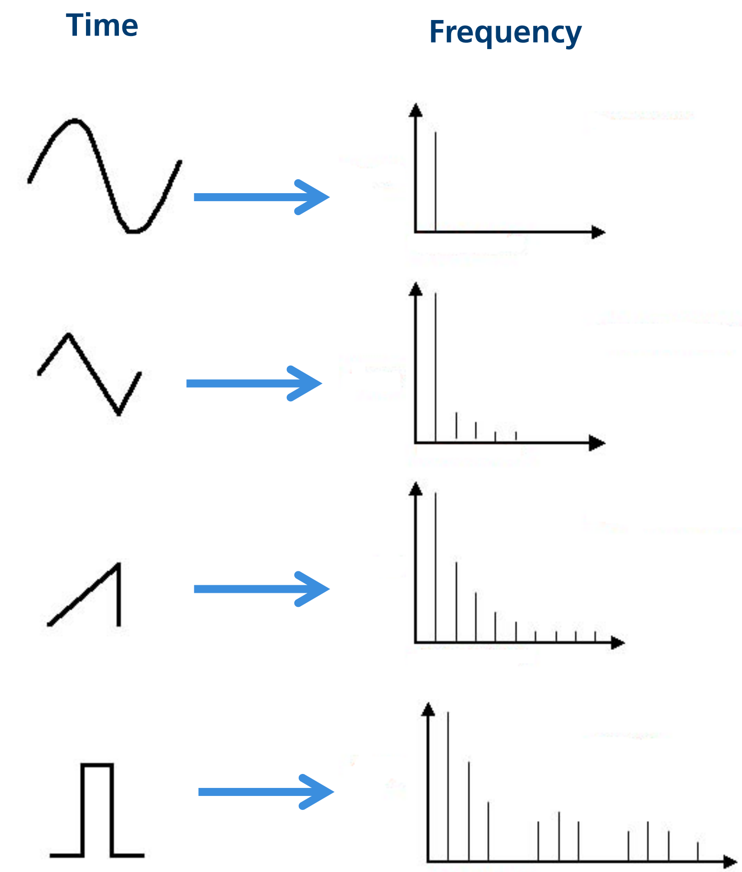
- Numerous projects observed where VSD interharmonic excitation triggers the 1st torsional mode of the system
- Operator is often struggling with understanding the excitation source
- The vibration signature may be dismissed as gear vibration levels are relatively low
- API 617 8th Ed. does highlight the source, but many vendors omit this analysis in torsional report

Fundamental theory – VSD module

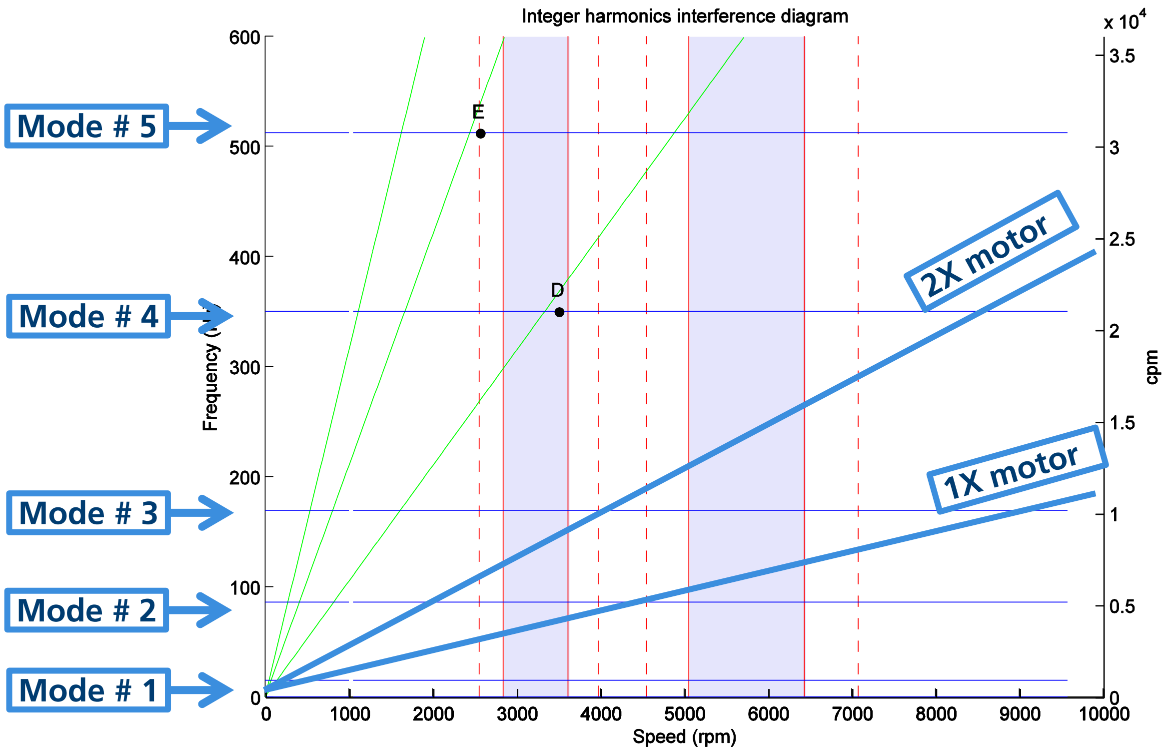


$$f_{interharmonic} = | n_G.p_G \cdot f_G \pm n_M.p_M \cdot f_M |$$

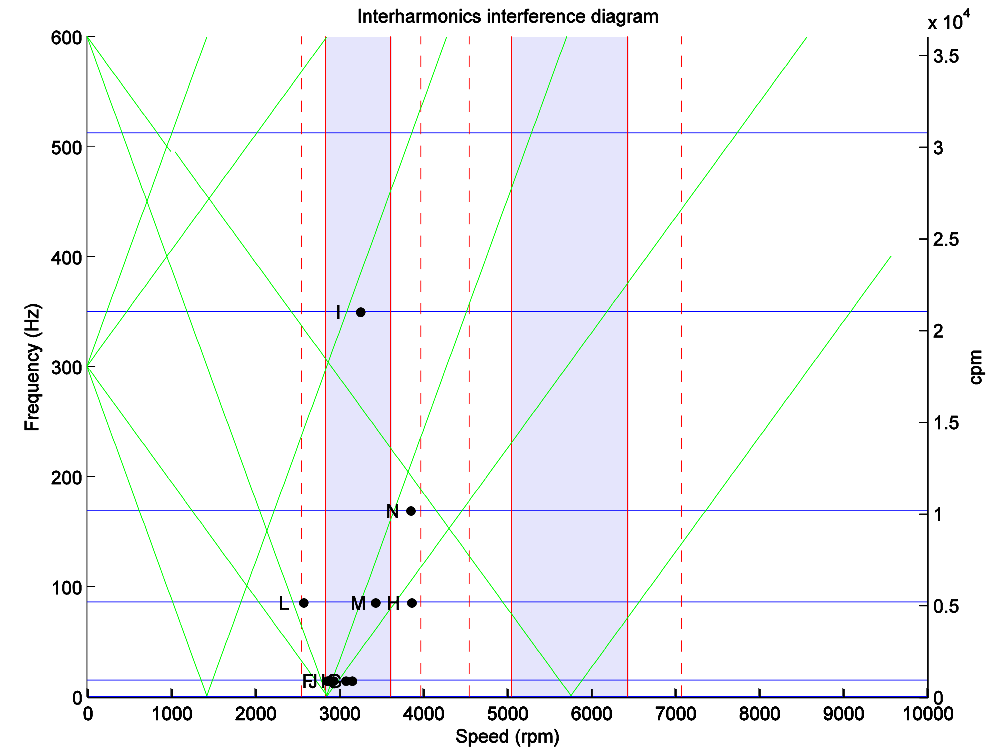




Fundamental theory – Campbell diagrams

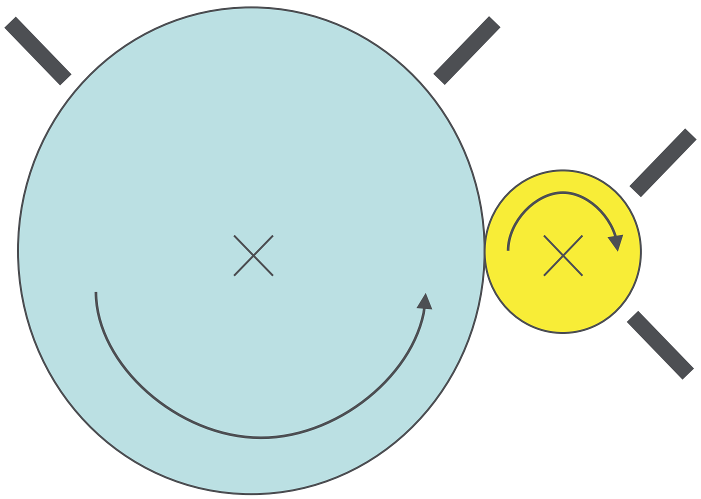


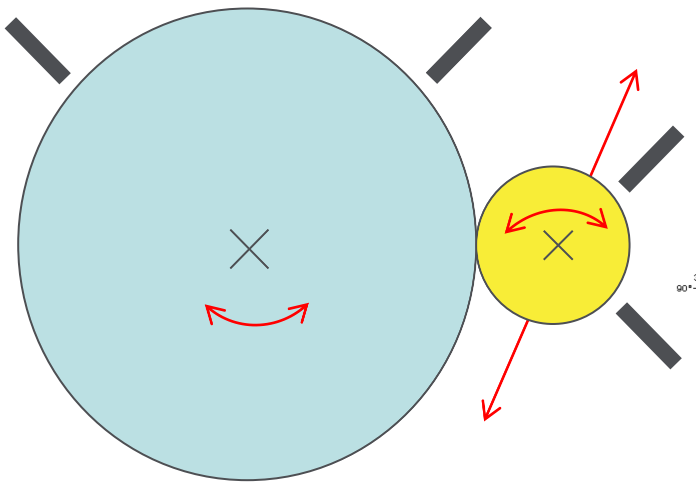
Motor speed [rpm]

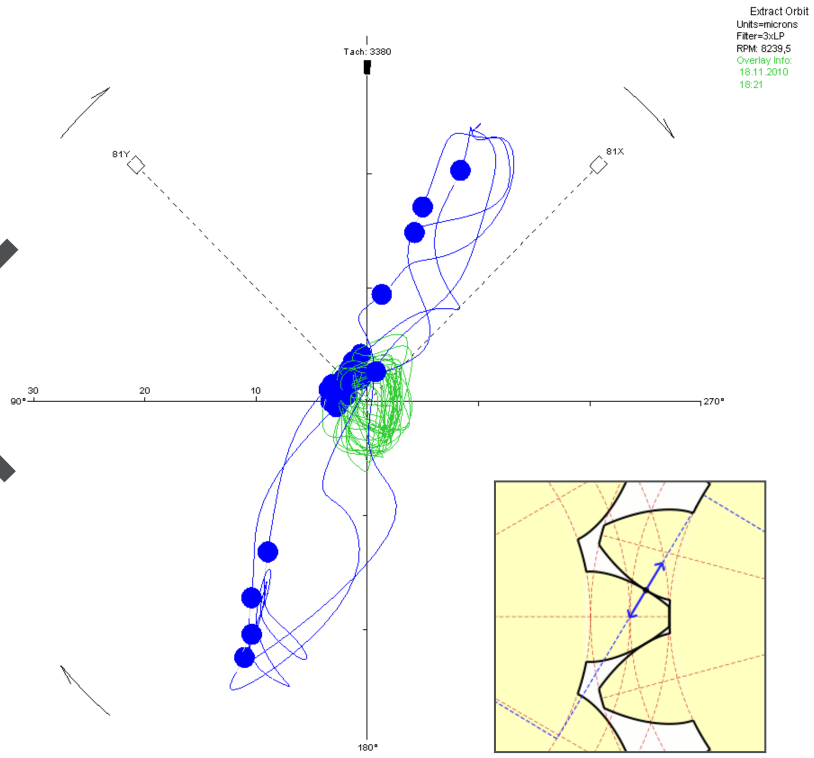


Motor speed [rpm]

Torsional – Lateral Coupling

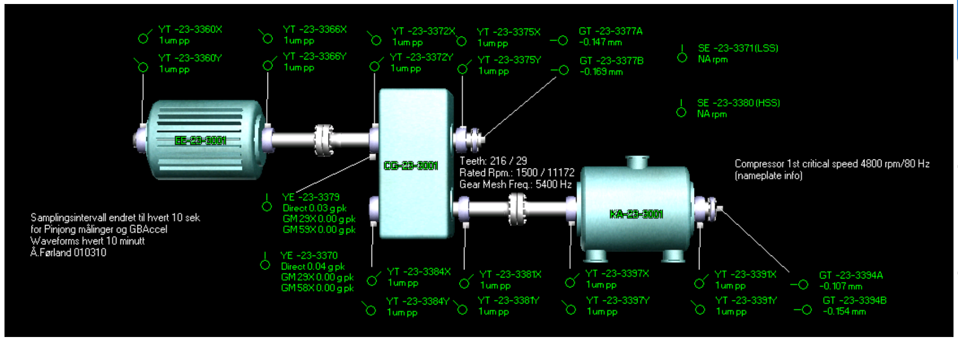




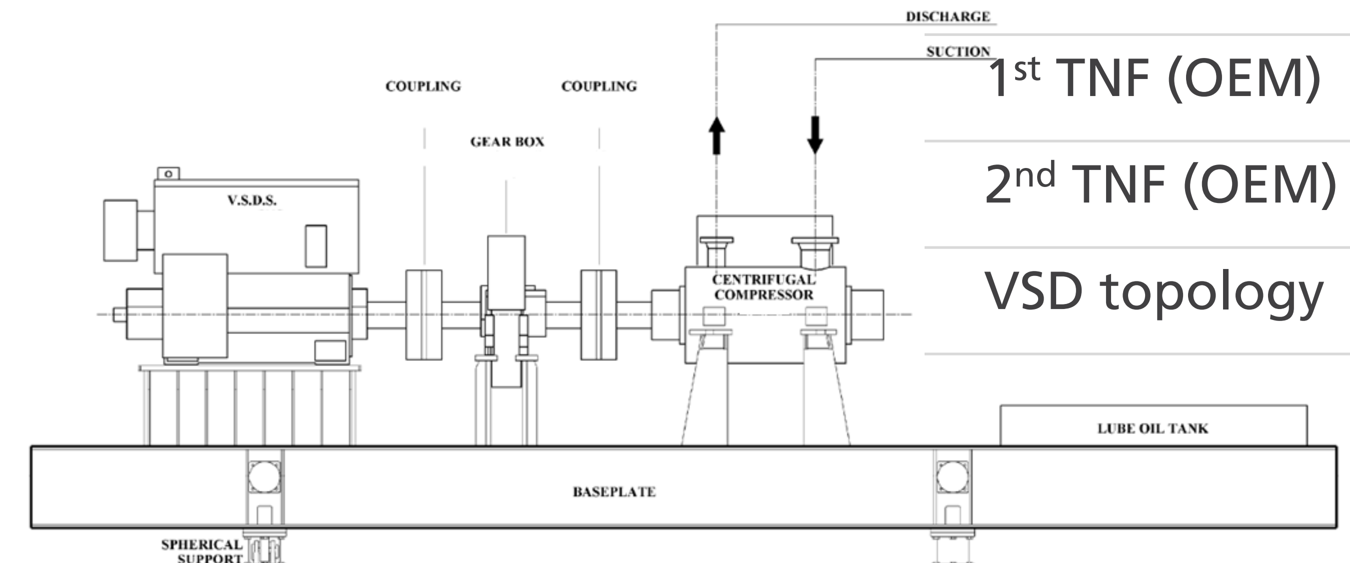


- Tangential forces in the tooth mesh.
- Visible on the pinion shaft due to the small weight/inertia
- Vibration trajectory coincides with the pressure angle in the gear teeth.

Case study: Low Pressure Compressor (Statoil)



Gear ratio	216 / 29 = 7.45
OSR, low speed side	1046 – 1500 rpm
OSR, high speed side	7794 – 11172 rpm
1st lateral critical (OEM)	5100 rpm
1st TNF (OEM)	1746 cpm (29.1 Hz)
2nd TNF (OEM)	3817 cpm (63.6 Hz)
VSD topology	3-level NPC Inverter



Initial Operation of the LP-compressor

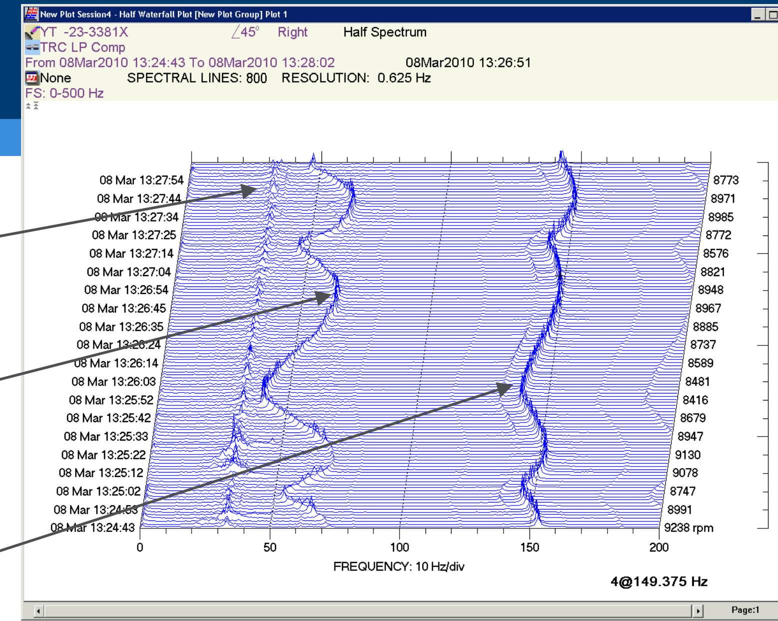
- Sudden increase of gearbox pinion vibrations, above alarm limit
- Initial diagnosis: gearbox mechanical problem.
- FFT-analysis indicated torsional resonance, coupled via gear mesh
- Excitation confirmed to be VSD-related. The inter-harmonic component I $9 \cdot f_{motor} - 6 \cdot f_{grid}$ I coincides with the mechanical natural frequency (32.5 Hz) at 8.200 RPM (Compressor Speed)

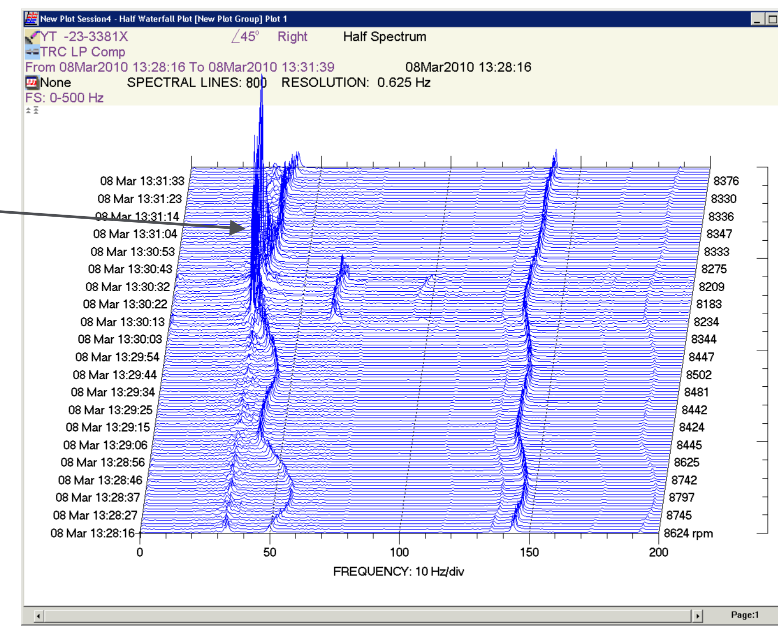
Torsional mode frequency, 32.5 Hz

Pulsating Torque Component
$f_{Ex} = \text{I } 9 \cdot f_{motor} - 6 \cdot f_{line} \text{ I}$

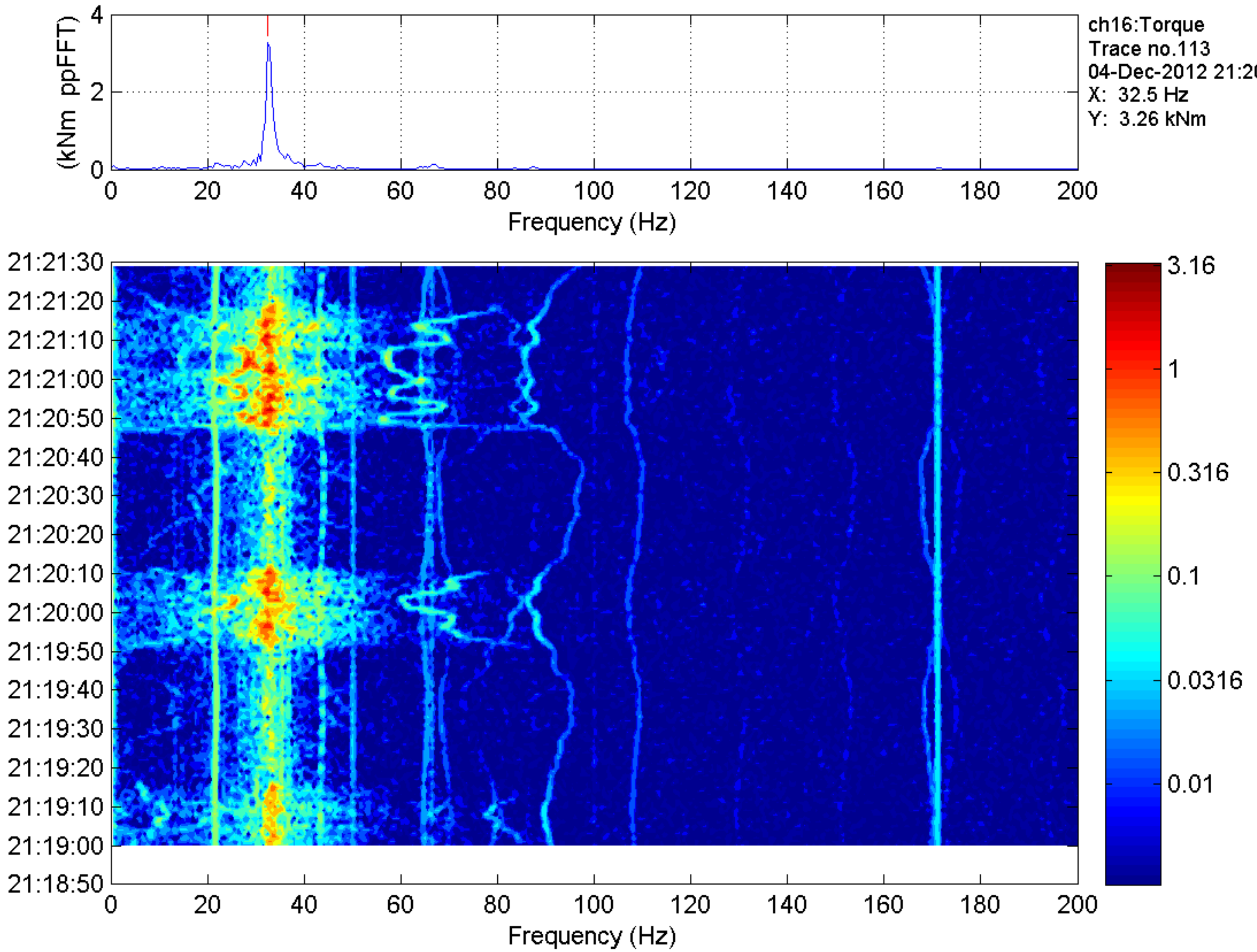
Synchronous speed component (1X vibration)

Torsional Resonance

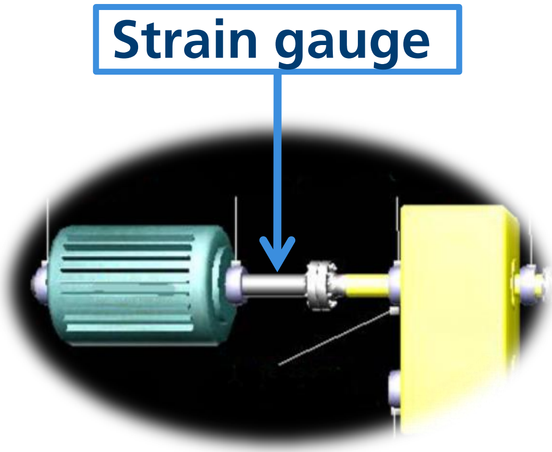




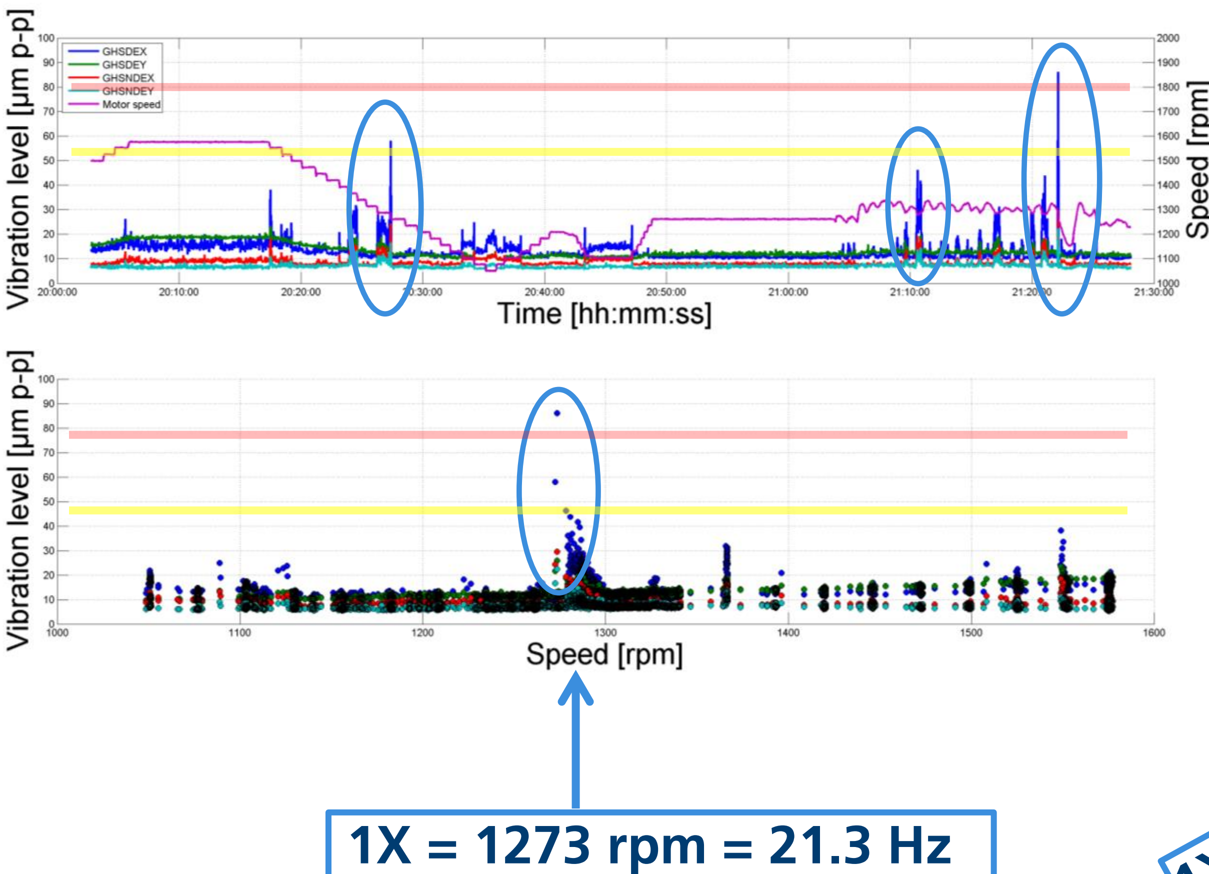
Strain gauge

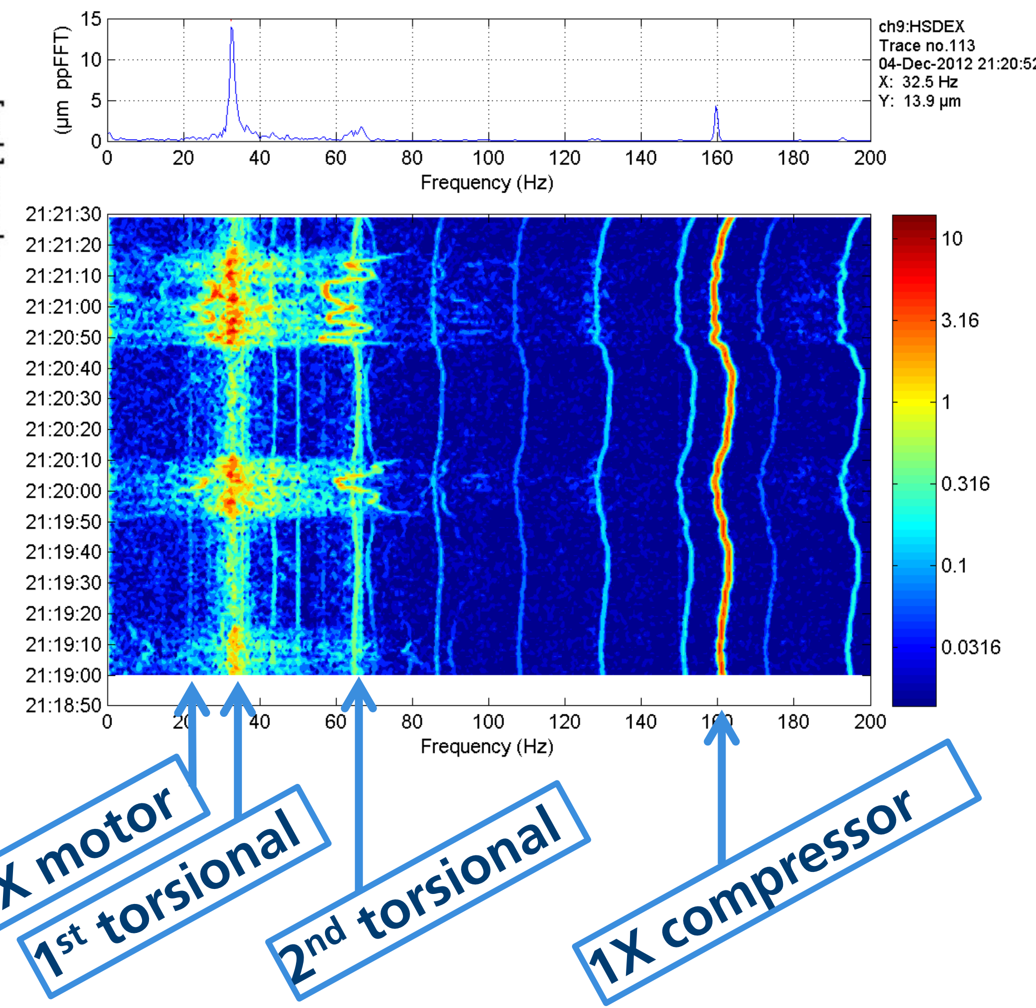


200 Hz, 400 lines, 0 integr., 1 avg., 50% overlap, Hanning, no HP filter, 150 spectra

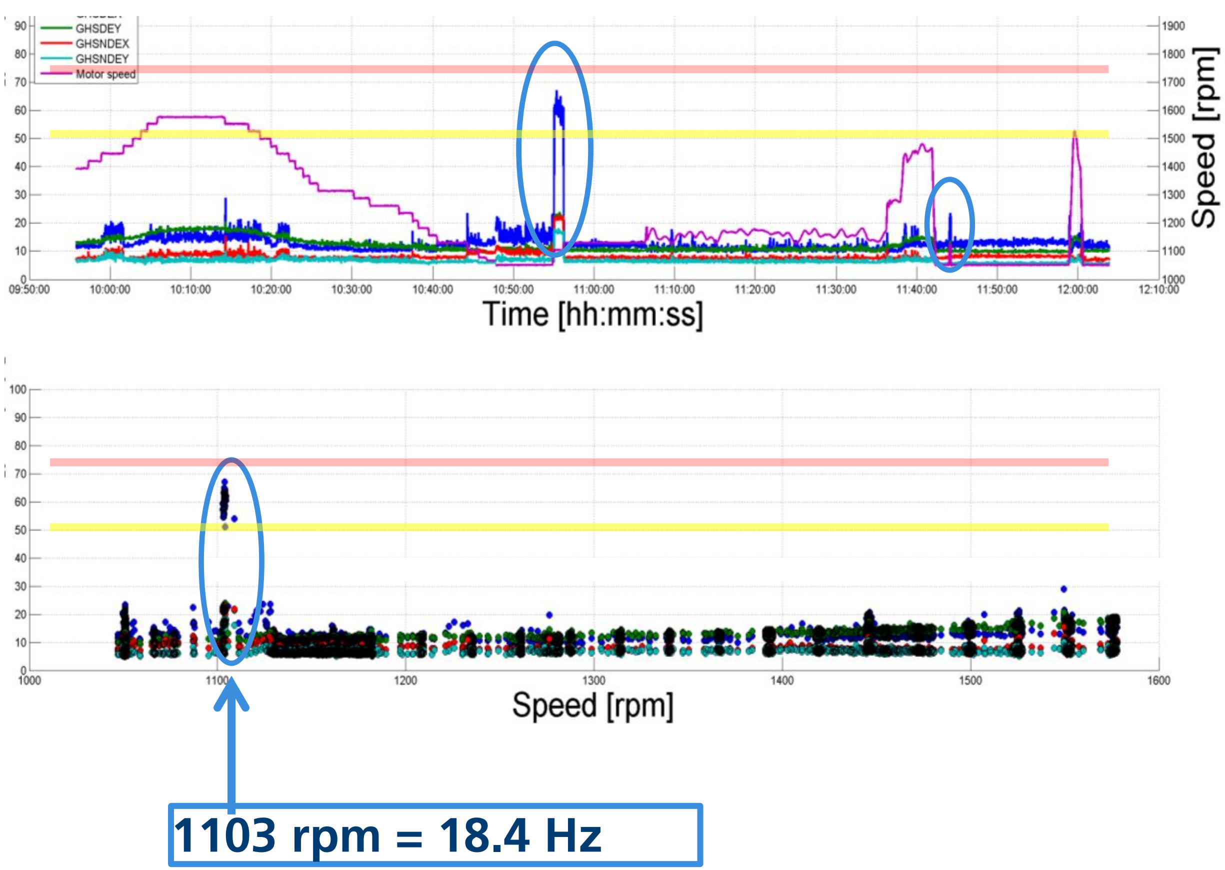


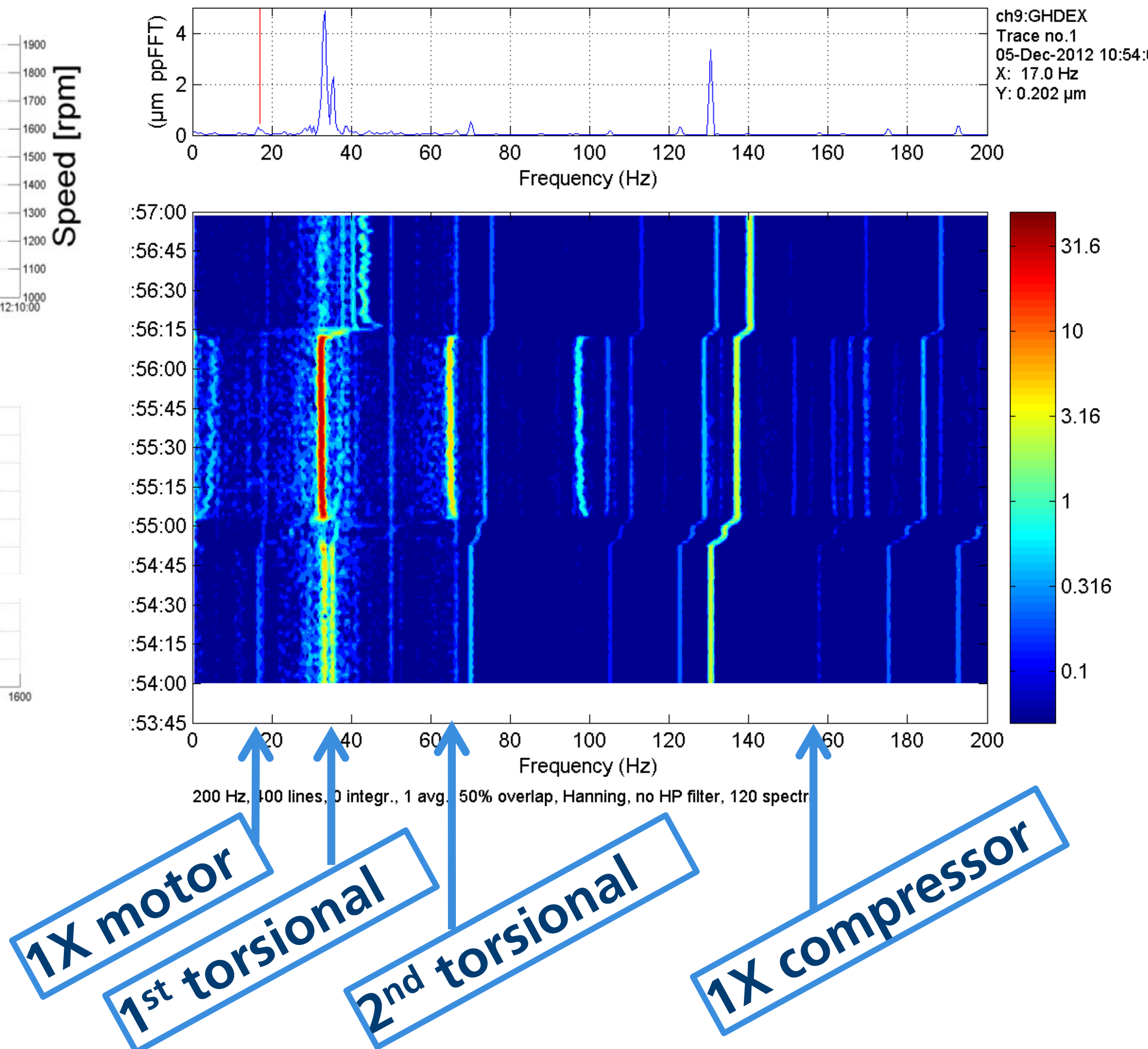
Measurements, pulse pattern 3





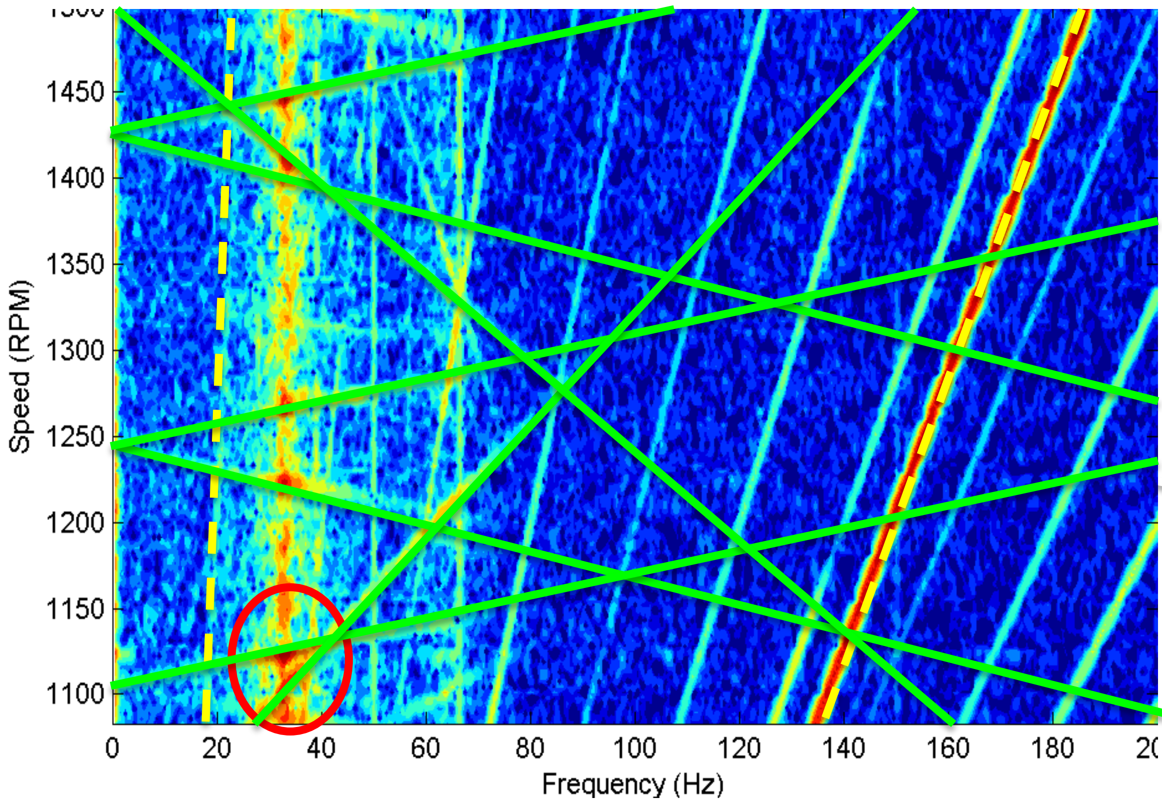
Measurements, pulse pattern 2



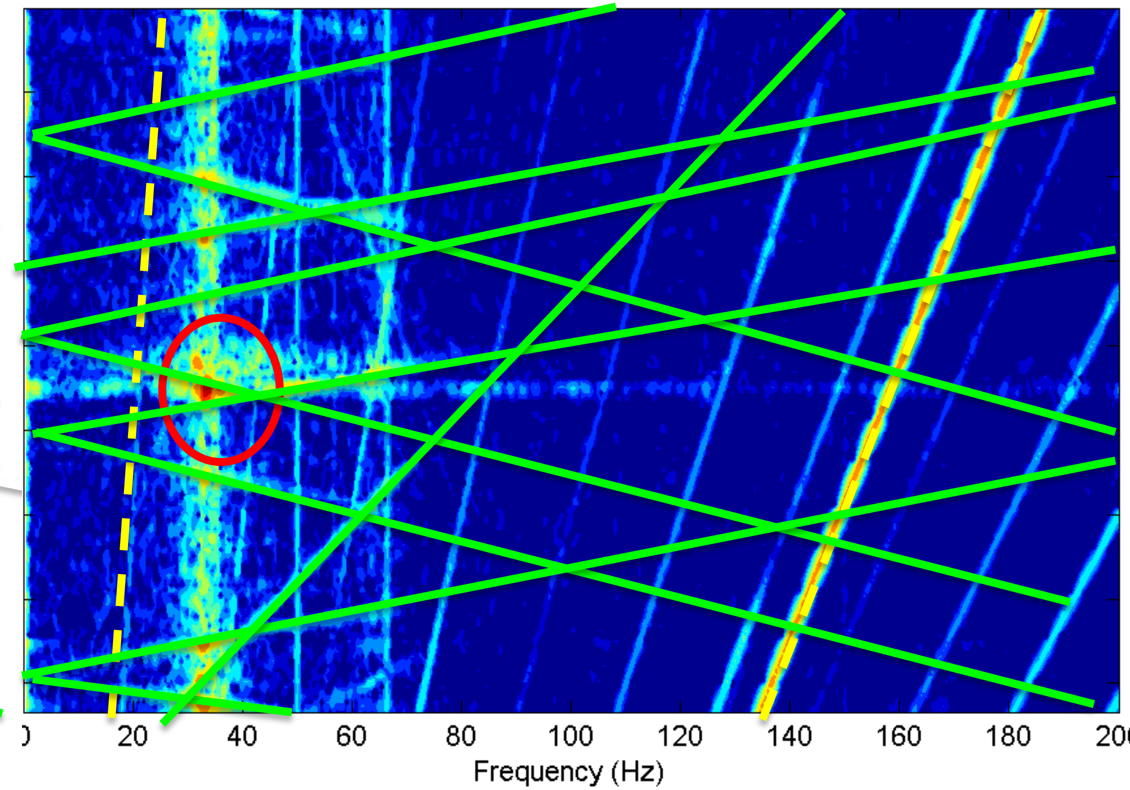


Pinion mode excitation

Pulse pattern 2



Pulse pattern 3



Motor speed

VSD interharmonics

- **Adjustment of VSD parameters (pulse pattern) has not eliminated the problem.**
- **Final solution: Implement “No-go-zones”; Specific narrow RPM-bands where steady state operation is not allowed.**

Lessons learned

- Torsional vibrations, Risk factors:
  - Machinery with variable electrical frequencies (VSD motors) or variable electrical load (generators)

- On machinery with parallel shaft gears, torsional vibrations will often appear as radial vibrations on the pinion shaft.

- On machinery without such gears, torsional vibrations will most likely not be detected (unless failure occurs), but may still be present!

- Once detected, no quick fix…
  - Adjusting VSD parameters to eliminate excitation for all RPMs -> not evident
  - Change of coupling stiffness -> most cases not possible, due to other constraints (load capacity, separation margins to other torsional (and lateral) modes.

Conclusions

- If the combination VSD + gear exist, make sure torsional analysis consider interharmonic excitations
- If problems in the field is encountered and interharmonic excitations is suspected, measure the shaft torque (e.g. strain gauges, torque meter etc.) and assess the actual fatigue life of the coupling(s)
- If interharmonic excitation is confirmed, three options exist:
    - Modify the mechanical system
      Change coupling to increase or decrease torsional resonance
    - Establish “road-maps”
      No-go zones can be mapped so the operators can avoid long term operation in these areas
    - Tune the VSD
      Contact VSD vendor and perform test where VSD technician, vibration experts and operator communicate and agree on a optimal VSD setting

Questions?